Internal Government Studies

1995

Reports and Presentations

Study Name: Electra-Optical Imager & Radiometer

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IPO POC: Lt. Kevin Westley

INTERNAL GOVERNMENT STUDIES - FY 1995
Electra-Optical Imager & Radiometer

Presentation/Paper Title	Author(s)	Date
"Final Report, Electro-Optical Imager and Radiometer(EOIR): An NPOESS Internal Concept Study"	J. Alishouse C.R. Rao	SEPT 95
"EO Sensor Design Studies, ICS Final Presentation and Report"	G. Rossano	28 SEPT 95
"EO Sensor Design Studies, ICS Final Presentation"	C.R.Rao	28 SEPT 95
"Calibration of the NPOESS E-O Sensor, ICS Final Presentation"	J. Alishouse	28 SEPT 95
"E-O Sensor Hardware Design Characteristics, Final Report and Future Study Recommendations"	-----------	SEPT 95
"E-O Band Selection for NPOESS Based on Key Parameters"	D. Lynch	SEPT 95
"EO Imager Baseline Requirements Presentation"	-------------	JUNE 95
"ICS Interim Status Review Meeting, Electro-Optical Imager & Radiometer"	D. Lynch	29 JUNE 95
"ICS Interim Status Review, EO Imager & Radiometer:	C.R. Rao	29 JUNE 95
"ICS Interim Status Review, Calibration Issues for the NPOESS E-O Sensor"	J. Alishouse	27 JUNE 95
"EO Imager ICS- June Progress Report"	Lt. K. Westley	20 JUNE 95
"EO Imager ICS- May Progress Report"	Lt. K. Westiey	16 MAY 95
"EO Imager ICS- April Progress Report"	Lt. K. Westley	2 MAY 95
"EO Sensor Baseline Design, EO Sensor Progress Report Briefing", (draft copy)	G. Rossano	21 APRIL 95

EO Sensor Design Studies
Final Report

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Remote Sensing Department
Space and Environment Technology Center
The Aerospace Corporation

SECONDARY STUDY AREAS

- Calibration options
- Thermal characteristics

FUNDAMENTAL APPROACH

- The objectives of providing constant solid angle data and constant footprint data are mutually exclusive for focal planes based on single detectors per footprint.
- To resolve this conflict the baseline focal plane makes use of two groups of wavelength bands.
  - high radiometric accuracy, constant solid angle, moderate spatial resolution bands.
  - high spatial resolution, "constant" footprint", moderate radiometric accuracy bands.
- It is assumed that high radiometric accuracy, high spatial resolution bands will not be required.

IMAGE DATA

- "Near constant" footprint, high image quality data.
- Any variations in footprint to vary as smoothly over the image area as practical.
- Provision for 7 bands (visible and IR) currently incorporated into the design.
- Provision for 1 additional low light (nightime visible) band currently incorporated into the design.
- Final number of wavelength bands TBD.
- Final bandpasses TBD.

RESOLUTION APPROACH

- Reported data will represent averages over some weighting function (the system Point Spread Function - PSF)
- EDR image characteristics will be investigated using the amplitude of the fourier transform of the system PSF (the system Modulation Transfer Function - MTF)
- One half the spatial wavelength for which the system MTF has a value of 0.4 must be less than or equal to the most stressing value given in the EDR horizontal resolution specifications.
- The system MTF is assumed to be in no other way constrained

ORBITAL CHARACTERISTICS

- 824 Km altitude orbit
  - ground track of 6.6 Km/sec

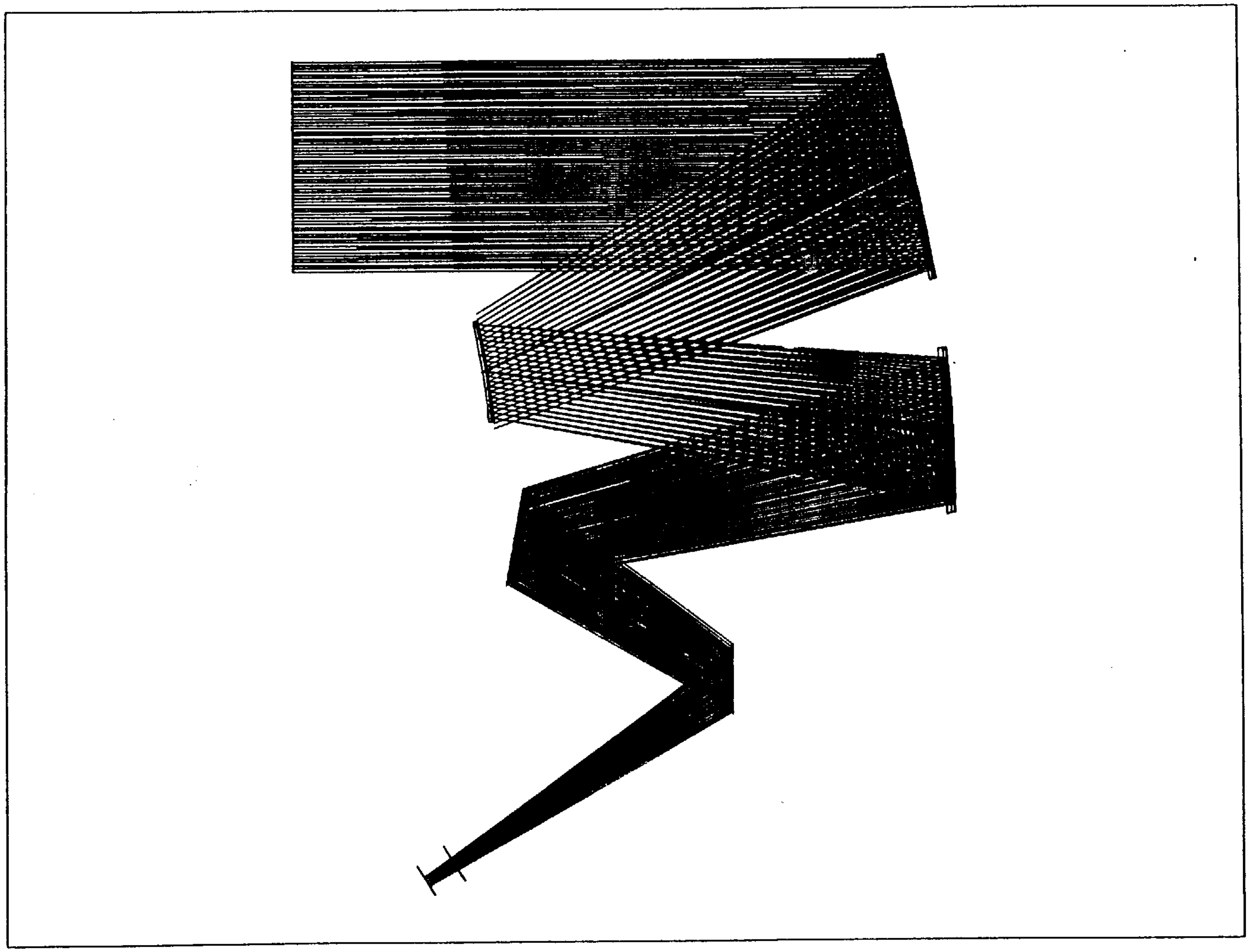
- Scan angle coverage of $\pm$ 56 degrees
  - ground swath of 2990 Km

- No special efforts in regard to polarization characteristics
- Image derotation using a half speed mirror.
  - minimizes distortions introduced by image rotation over scan angle
- Telescope rotation at 1 Hz, constant angular scan rate
  - simplifies scanner
  - requires lower torque
  - avoids need for momentum compensation
- Nominal dwell time 25 μsec (18.6 - 50 μsec typical)
  - driven by resolution requirements which constrain maximum permitted smearing due to scanner motion

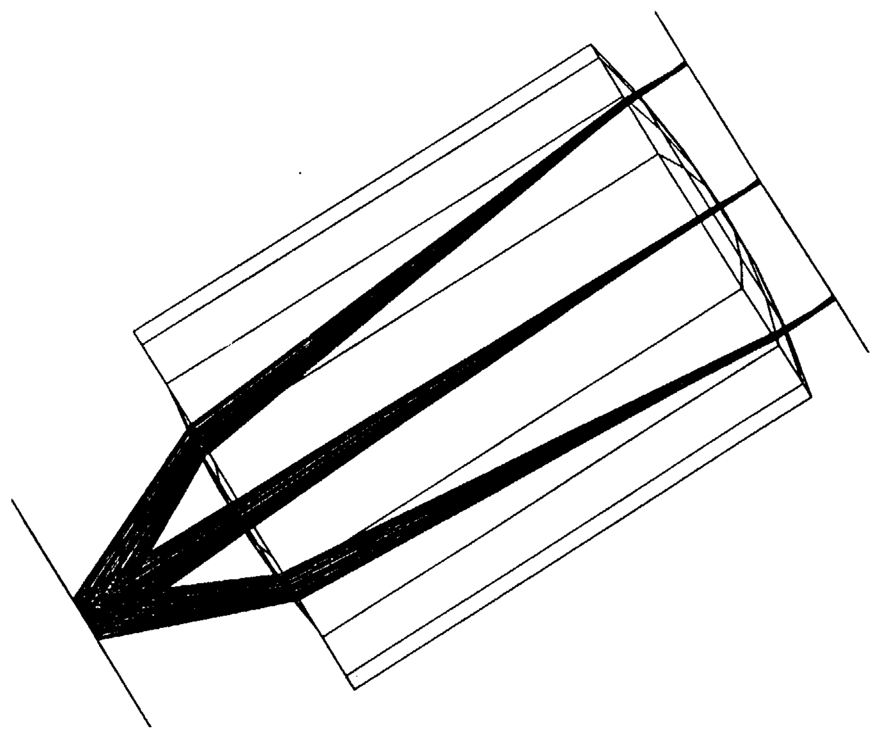
OPTICAL CHARACTERISTICS

- 824 mm focal length.
- All reflecting optics (up to focal plane).
- Fabry lens for radiometric channels at focal plane.
- Wavelength coverage from 0.4 - 12.0 μm.
- Focal plane coverage of 6.6 mm x 20.0 mm.
- Geometric spots as symmetric as practical to minimize image distortion.
- Geometric spots as uniform throughout focal plane as practical to support accurate inter-band comparison.
- Geometric spots as small as practical to support meeting resolution requirements.

FORE-OPTICS



FABRY LENS DETAIL



WIRE FRAME

NPOESS
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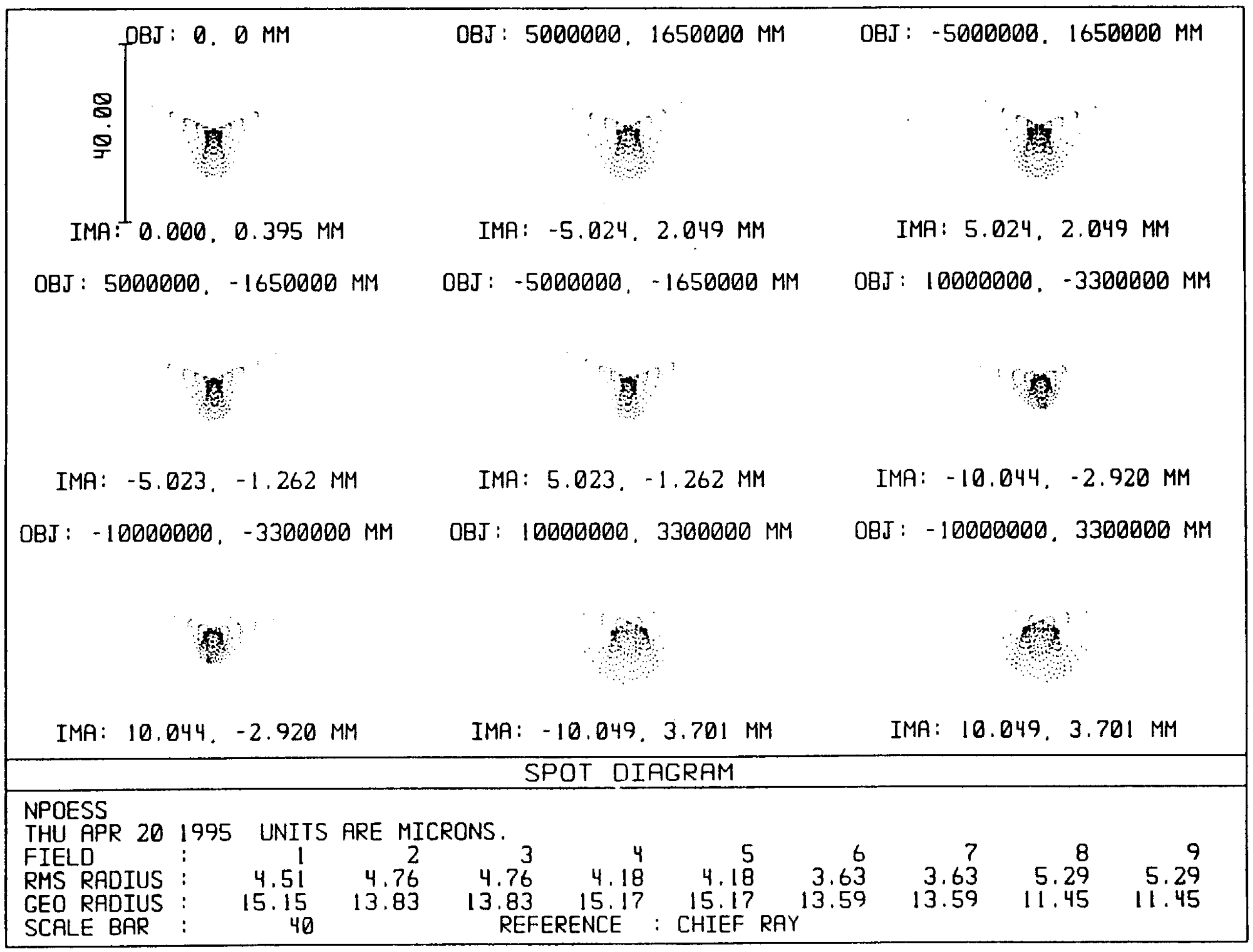
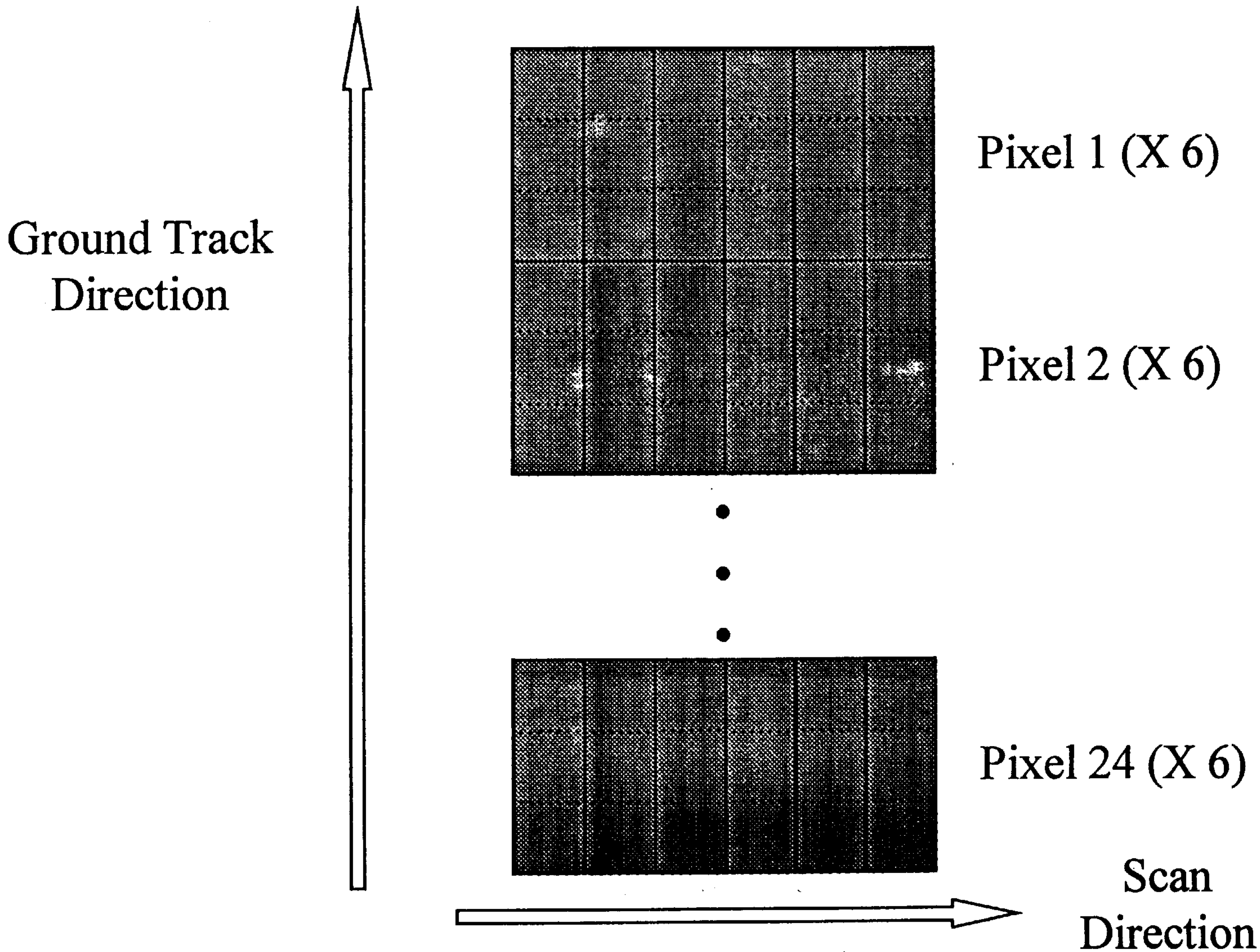
SPOT DIAGRAMS THROUGHOUT FOCAL PLANE



TDI DETAIL



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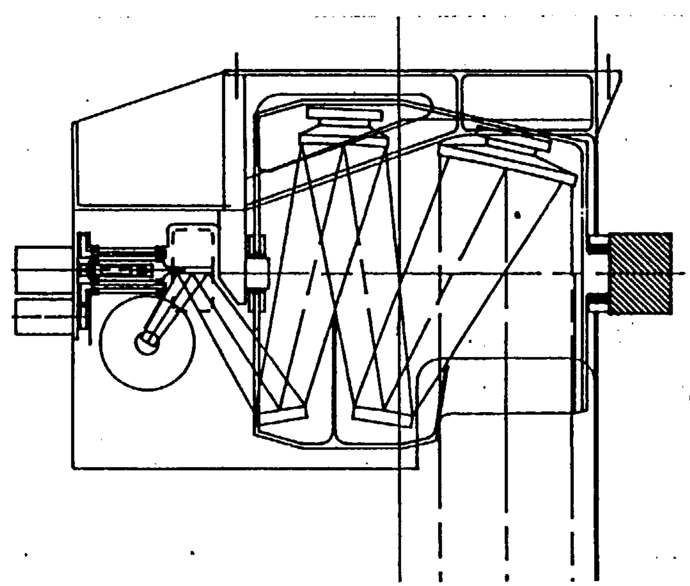
SCANNER LAYOUT



CALIBRATION METHODS

- Solar Diffuser
- IR black body
- Cold Space view
- Visible lamps

CONTRIBUTIONS TO SYSTEM RESOLUTION

- Optical MTF (geometric spots and diffraction)
- Spatial averaging over the field stop
- Detector output filtering
- Scanner and spacecraft motions
- Data algorithms

SYSTEM RESOLUTION EXAMPLES

	Instantaneous		Smeared	
	In-Scan	In-Track	In-Scan	In-Track
5.56 μm				
nadir	0.078 km	0.20 km	0.100 km	0.20 km
end of scan	0.48 km	0.44 km	0.61 km	0.44 km
7.85 μm				
nadir	0.084 km	0.20 km	0.105 km	0.20 km
end of scan	0.52 km	0.44 km	0.64 km	0.44 km
11.11 μm				
nadir	0.092 km	0.20 km	0.111 km	0.20 km
end of scan	0.56 km	0.44 km	**0.68 km**	0.44 km
12.0 μm				
nadir	0.101 km	0.21 km	0.122 km	0.21 km
end of scan	0.62 km	0.45 km	**0.75 km**	0.45 km

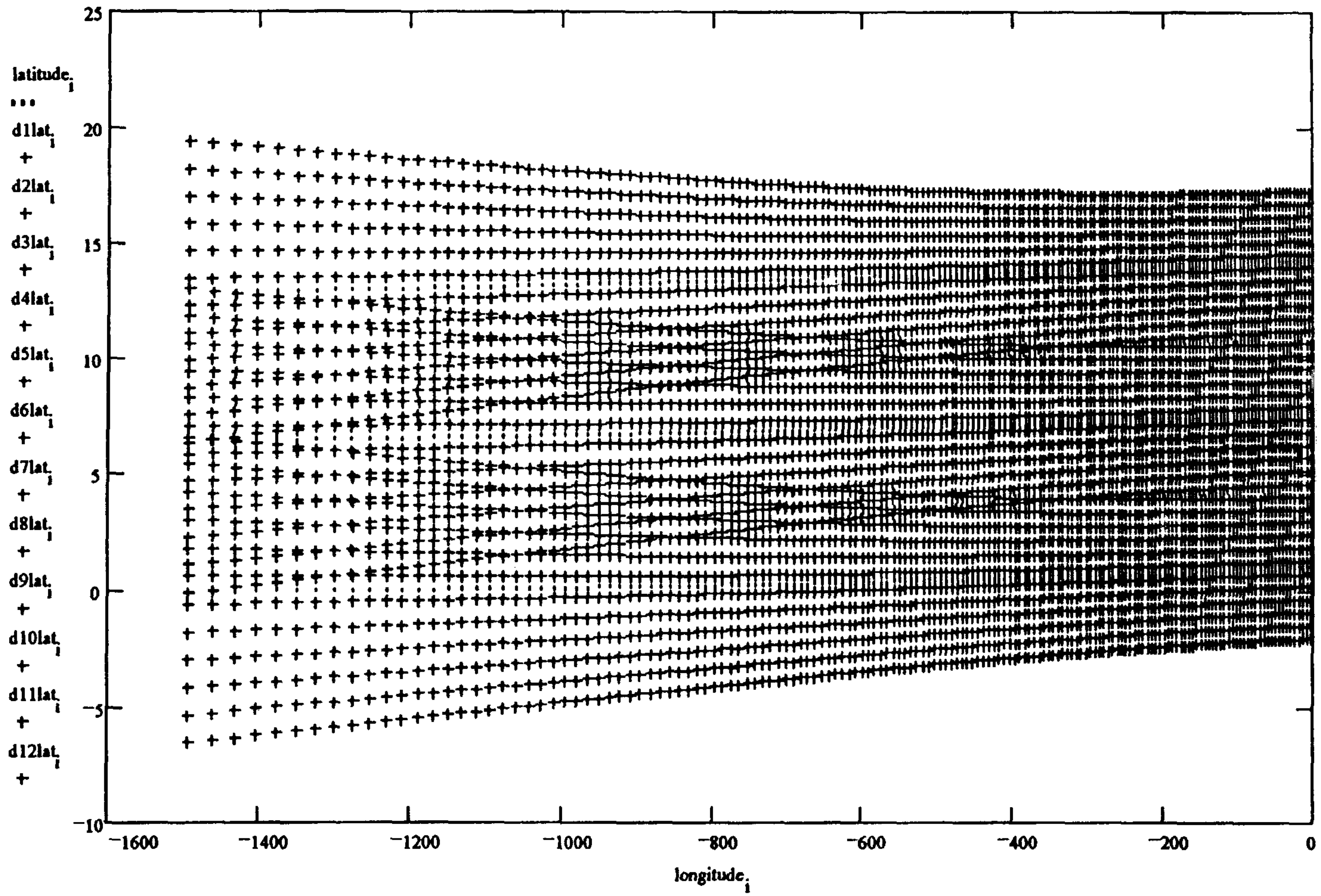
FOOTPRINT CONTROL

- Is not required for constant solid angle, radiometric, pixels
- Has been considered for imaging pixels
  - variable magnification reimaging optics
  - pixel aggregation using segmented detectors incorporated into the focal plane
  - variable size field stop at the focal plane
- Various methods to control footprint size have different implications for complexity, data rate, and sensitivity

SAMPLING INTERVAL

- Ability to discern features is determined by resolution, sampling, and sensitivity.
- For gaussian system PSFs the ideal sampling rate is twice per resolution element.
- For square system PSFs the ideal sampling rate is about 6 times per resolution element.

SAMPLE GROUND TRACKS



TARGET SENSITIVITY, IMAGING BANDS

Band	Center Wavelength	Bandwidth	Maximum Scene	Minimum Scene	SNR/NEΔT
0.61	0.615 ~~mm~~ μm	0.02 ~~mm~~ μm	1.0 Solar	0.005 Solar	20
0.87	0.87 ~~mm~~	0.02 ~~mm~~	1.0 Solar	0.005 Solar	20
1.61	1.61 ~~mm~~	0.24 mm	1.0 Solar	0.005 Solar	20
3.75 (1)	3.75 ~~mm~~	0.30 mm	340 K	260 K	0.9 K
3.75 (2)	3.75 ~~mm~~	0.30 ~~mm~~	340 K	300 K	0.2 K
8.5 (1)	8.55 ~~mm~~	0.30 ~~mm~~	340 K	190 K	2.0 K
8.5 (2)	8.55 ~~mm~~	0.30 ~~mm~~	340 K	300 K	0.2 K
10.8 (1)	10.8 ~~mm~~	1.00 ~~mm~~	340 K	190 K	0.9 K
10.8 (2)	10.8 ~~mm~~	1.00 ~~mm~~	340 K	300 K	0.2 K
12.0 (1)	12.0 ~~mm~~	1.00 ~~mm~~	340 K	190 K	0.9 K
12.0 (1)	12.0 ~~mm~~	1.00 ~~mm~~	340 K	300 K	0.2 K
LL	0.70 ~~mm~~	0.60 ~~mm~~	0.0025 Solar	1.5 X 10^{-7} Solar	6

CALCULATED SENSITIVITY, IMAGING BANDS

Band	Center Wavelength	Detector	Dwell Time	1/f factor	SNR/NEΔT
0.61 I	0.615 ~~mm~~ μm	pv Si	18 msec	1	37.7
0.87 I	0.87 ~~mm~~	pv Si	18 msec	1	33.3
1.61 I	1.61 ~~mm~~	pv Si	18 msec	1	42.1
3.75 I1	3.75 ~~mm~~	pv HgCdTe	18 msec	1	**1.3 K**
3.75 I2	3.75 ~~mm~~	pv HgCdTe	18 msec	1	**0.28 K**
8.5 I1	8.55 ~~mm~~	pv HgCdTe	18 msec	1	1.8 K
8.5 I2	8.55 ~~mm~~	pv HgCdTe	18 msec	1	0.18 K
10.8 I1	10.8 ~~mm~~	pc HgCdTe	18 msec	1.1	0.84 K
10.8 I2	10.8 ~~mm~~	pc HgCdTe	18 msec	1.1	0.17 K
12.0 I1	12.0 ~~mm~~	pc HgCdTe	18 msec	1.1	**0.99 K**
12.0 I2	12.0 ~~mm~~	pc HgCdTe	18 msec	1.1	**0.25 K**
LL I	0.70 ~~mm~~	pv Si	18 msec	1	**0.034**

DATA RATES

7 Radiometric Bands

2 samples per pixel
12 bits per pixel
with

no compression	1.41 Mbits/sec
2x lossless compression	0.70 Mbits/sec

1 sample per pixel
12 bits per pixel
with

no compression	0.70 Mbits/sec
2x lossless compression	0.35 Mbits/sec

8 Imaging Bands

2 samples per 0.65 Km
12 bits per pixel
with

no compression	20.2 Mbits/sec
2x lossless compression	10.1 Mbits/sec
5x lossy compression	4.04 Mbits/sec

2 samples per 0.65 Km
10 bits per pixel
with

no compression	16.8 Mbits/sec
2x lossless compression	8.41 Mbits/sec
5x lossy compression	3.36 Mbits/sec

DIFFICULTY IN MEETING INSTRUMENT CHARACTERISTICS

	Radiometric Bands	Imaging Bands	Low Light Visible Band
Resolution	low	moderate	low
Sensitivity	low	high	**extremely high**
Calibration	**extremely high**	moderate	moderate
Data Rate	low	high	moderate

RESOLUTION TRADES, TO IMPROVE IR RESOLUTION

OPTION	SIDE EFFECT
1. Increase mirror size in the in-scan direction by 25% to reduce diffraction.	1. Requires a corresponding increase in scanner size and mass, and will result in slightly degraded performance at shorter wavelengths due to an increase in geometric spot sizes.
2. Decrease the dwell time by a factor of 2 in the IR bands to reduce image smearing in the in-scan direction.	2. Results in a loss in sensitivity at all wavelengths for which a reduced dwell time is used.
3. Slow the scanner to 1/2 Hz operation while keeping dwell time constant.	3. Reduces image smearing with no loss of sensitivity, but introduces dead times into the data acquisition process - and in effect throws away a factor of the square root of two in potential gains in sensitivity obtainable by operating at a lower scan rate.
4. Increase the altitude of the orbit to reduce the overall scan angle, and thus the factor by which the footprint grows at the end of scan.	4. Requires change in system focal length or focal plane geometry.

SENSITIVITY TRADES, TO IMPROVE IR AND LL SENSITIVITY

OPTION	SIDE EFFECT
1. Reduce scanner speed to increase dwell time.	1. Increases the effect of 1/f noise. Increases the number of pixels required in-track - requires faster optics and degrades resolution at short wavelengths.
2. Increase collecting area of optics.	2. Requires faster optics and degrades resolution at short wavelengths. Increases scanner size and mass. LL requires 2.5 m telescope.
3. Increase the number of TDI elements.	3. Increase in one band requires corresponding decrease in another band. - or - Requires faster optics and degrades resolution at short wavelengths.
4. Degrade LL resolution.	4. Coarser detail provided in LL images.

PRIMARY STUDY AREAS

- Resolution performance
- Sensitivity performance
- Data rates and data sampling
- Scanner characteristics
- Focal plane characteristics

BASELINE CONSTRAINTS

- Meet requirements for those EDRs primarily derived from EO sensor data.
  - In the absence of a system-wide instrument suite study, a set of EDRs to be supported have been chosen to define the scope of the study.
- High radiometric accuracy data must be provided in some number of wavelength bands using constant solid angle pixels.
- High image quality data must be provided in some number of wavelength bands. Footprints permitted to vary with scan angle with maximum footprint not to exceed threshold requirements.

FUNDAMENTAL ASSUMPTIONS

- EDRs can be met using two groups of wavelength bands, divided as follows:
  - high radiometric accuracy, constant solid angle, moderate spatial resolution bands.
  - high spatial resolution, moderate radiometric accuracy bands.
- High radiometric accuracy, high spatial resolution bands will not be required.

RADIOMETRIC DATA

- Constant solid angle, high radiometric accuracy data.
- Provision for 7 bands (visible and IR) currently incorporated into the design.
- Final number of wavelength bands TBD.
- Final bandpasses TBD.

ACCURACY APPROACH

- Reported EDRs will be averages of the true brightness distribution spatially averaged over the two-dimensional system PSF
- Radiometric accuracy requirements are assumed to be met for an EDR when the differences between the values of the EDR reported and the true averages of the true brightness distribution meet the accuracy specification for the EDR

OPTICAL/SCANNER CHARACTERISTICS

- 3 element anastigmat reflecting optics provides high image quality over a 1.5 degree field of view.
  - required by large number of wavelength bands, multiple detectors, and other image quality data requirements.
- 254 cm^2 collecting area
  - 19.5 cm X 13.0 cm (7.7 in x 5.1 in)
  - equivalent in area to an 18 cm (7.08 in) diameter primary mirror
  - diffraction limited performance at long wavelengths drives system towards largest optics practical.
- Total system transmission goal $\geq$ 0.333
  - Driven by sensitivity requirements.

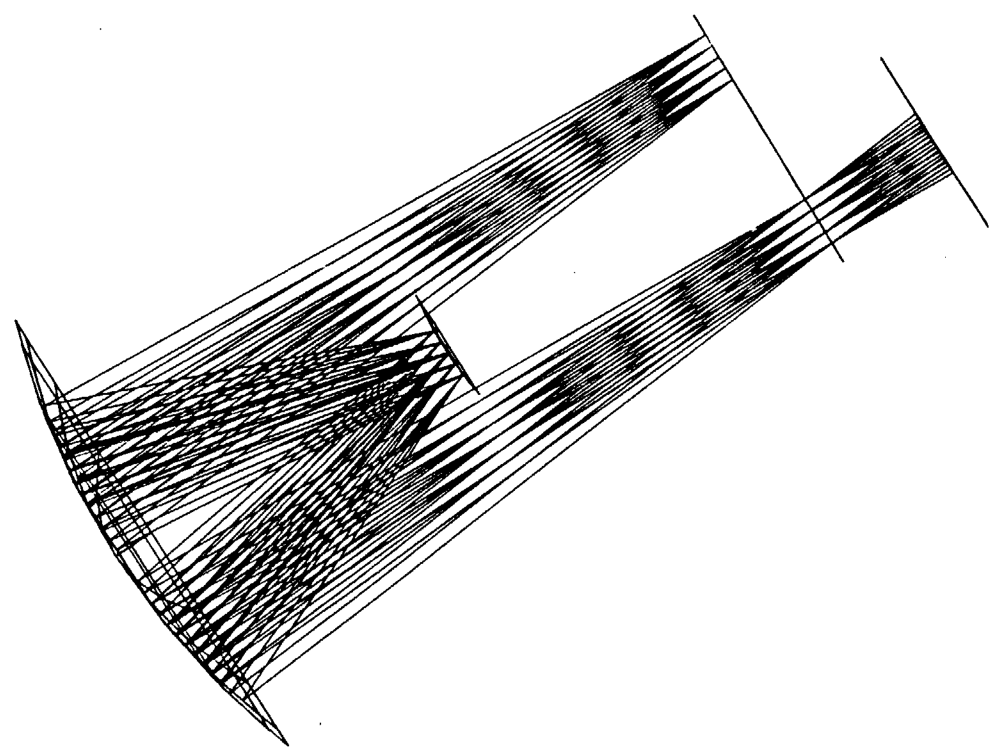
DUAL FOCAL PLANE CHARACTERISTICS

- Focal plane meeting requirements in the areas of bandpasses, resolution, SNR, and calibration requirements

- Dual data streams with individual characteristics tailored to EDR requirements
  - detector/ifov/footprint geometry
  - sample rates and intervals
  - dwell times
  - gain control
  - data compression

3-D representation here

RE-IMAGING OPTICS DETAIL

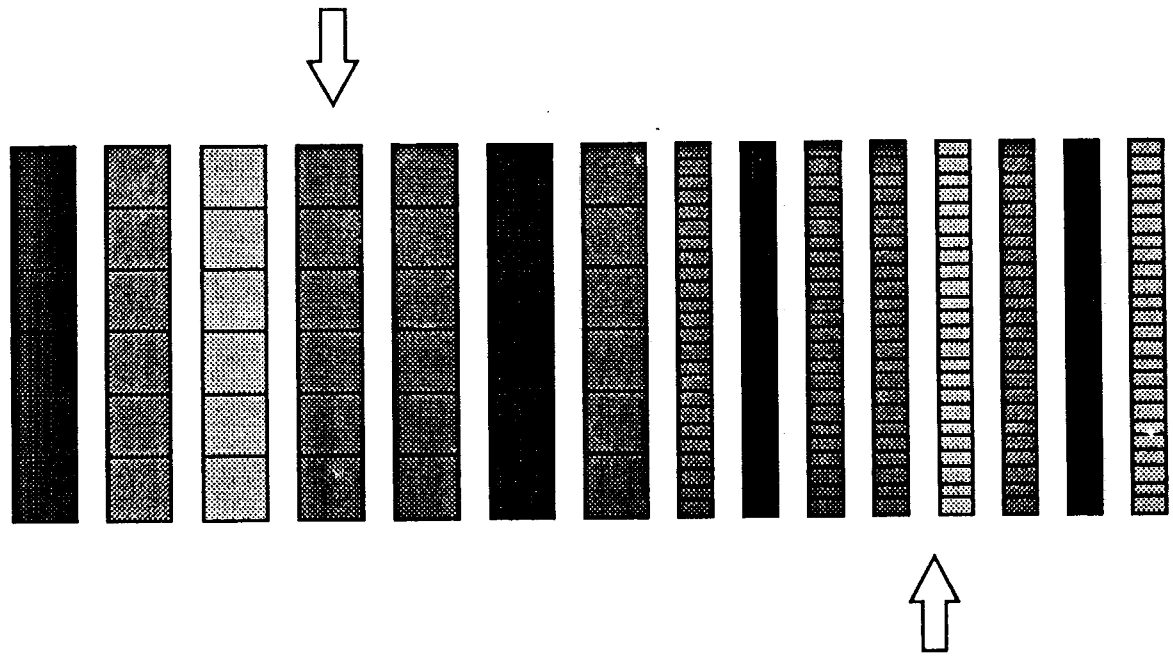


WIRE FRAME

NPOESS
TUE APR 25 1995

FOCAL PLANE LAYOUT

Radiometry pixels
1.1 km x 1.1 km x 1 at nadir

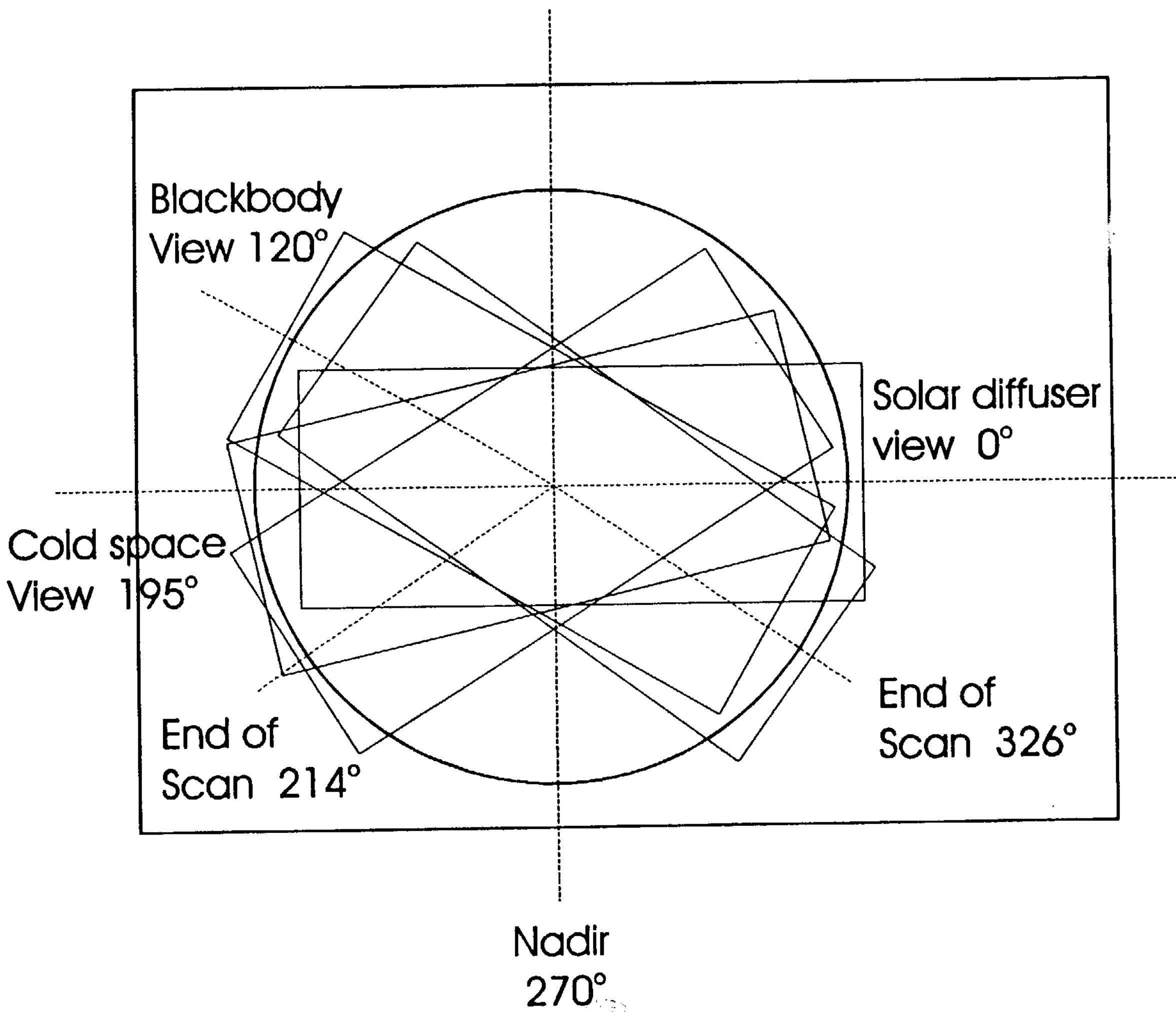


Imaging pixels
0.275 km x 0.092 km x 6 at nadir

SCANNER FEATURES

- Three telescope mirrors and one folding flat packaged in a single structure rotating at 1 Hz.
- Aperture stop at secondary, internal baffling, and small earth shield to control stray light.
- One-to-one offner reimaging to reduce thermal background at longer wavelengths. Offner secondary serves as an aperture stop.
- Eccentric mechanism on rotating half speed mirror to allow use of both its sides without focus shifts, or image shifts in the focal plane.

SCANNER VIEW ANGLES



THERMAL CHARACTERISTICS

- 2π steradian cold space view on anti-solar side of spacecraft.
- Focal plane temperature goal: 85 - 90 K.
- Offner cavity at 190 K limits thermal background for longer wavelength IR bands.
- Three stage passive radiator currently assumed.
- Total radiator area estimated at 3720 cm^2.
- Nominal radiator size 50 cm x 75 cm.

SYSTEM RESOLUTION

- Resolution is better than 0.65 Km for all scan angles, for all wavelengths shortward of 8 microns.
- From 8 - 12 microns, in-track resolution is better than 0.65 Km for all wavelengths.
- From 8 - 12 microns, in-scan resolution is better than 0.65 Km for 98 % of the swath.

FOOTPRINT GROWTH

- Uncompensated footprint growth for a scan range of $\pm$ 56 degrees and an altitude of 824 Km:
  - 6.14 X, in-scan
  - 2.16 X, in-track
- For constant solid angle pixels, footprint at end of scan is 6.8 Km (in-scan) x 2.4 Km (in-track) for 1.1 Km pixels at nadir.
- For "constant" footprint pixels, uncompensated footprint at end of scan is 0.6 ~~3.7~~ Km (in-scan) x 0.60 Km (in-track) for ~~0.6~~ Km x 0.275 Km pixels at nadir.

0.092

IMAGE DATA FOOTPRINT CONTROL

- Makes use of pixel aggregation to
  - reduce range of footprint growth over swath
  - reduce total data rate
  - increase sensitivity near center of swath

SAMPLING MODES

- Focal plane layout for the imaging bands supports (roughly) two samples per resolution element in-track and an "arbitrary" sampling rate in-scan - limited by data rate and sensitivity requirements.
- Focal plane layout for the radiometric bands supports one samples per resolution element in-track and an "arbitrary" sampling rate in-scan - limited by data rate and sensitivity requirements.

TARGET SENSITIVITY, RADIOMETRIC BANDS

Band	Center Wavelength	Bandwidth	Maximum Scene	Minimum Scene	SNR/NEΔT
0.61	0.615 ~~mm~~ um	0.02 ~~mm~~ μm	1.0 Solar	0.005 Solar	20
0.87	0.87 ~~mm~~	0.02 ~~mm~~	1.0 Solar	0.005 Solar	20
1.61	1.61 ~~mm~~	0.06 ~~mm~~	1.0 Solar	0.005 Solar	20
3.75	3.72 ~~mm~~	0.20 ~~mm~~	345 K	300 K	0.1 K
8.5	8.55 ~~mm~~	0.30 ~~mm~~	345 K	300 K	0.1 K
10.8	10.8 ~~mm~~	1.00 ~~mm~~	345 K	300 K	0.1 K
12.0	12.0 ~~mm~~	1.00 ~~mm~~	345 K	300 K	0.1 K

CALCULATED SENSITIVITY, RADIOMETRIC BANDS

Band	Center Wavelength	Detector	Dwell Time	1/f factor	SNR/NEΔT
0.61 R	0.615 ~~mm~~ μm	pv Si	18 msec	1	110.1
0.87 R	0.87 ~~mm~~	pv Si	18 msec	1	98.8
1.61 R	1.61 ~~mm~~	pv Si	18 msec	1	105
3.75 R	3.72 ~~mm~~	pv HgCdTe	50 msec	1	0.044 K
8.5 R	8.55 ~~mm~~	pv HgCdTe	50 msec	1	0.012 K
10.8 R	10.8 ~~mm~~	pc HgCdTe	50 msec	1.1	0.012 K
12.0 R	12.0 ~~mm~~	pc HgCdTe	50 msec	1.1	0.014 K

THE SENSITIVITY "BOTTOM LINE"

- Based on assumed sensitivity specifications (OMIS - VIRSR heritage) sensitivity requirements are met for 14 of 19 cases examined
- Performance in three wavelength bands is below assumed requirements
  - 4 micron band
  - 12 micron band
  - low light band

BULK SENSOR CHARACTERISITCS

- Size - 38 X 46 X 70 inches
- Mass - 230 lbs
- Power - 250 Watts

TECHNOLOGY MATURITY/RISK

- This study limited itself to mature technology of low to moderate risk.
- Miniaturization and integration of the focal plane is the area of least maturity.
- Less mature and higher risk approaches are identified for possible future study.

WAVELENGTH AND BANDPASS TRADES

OPTION	SIDE EFFECT
1. Increase number of bands.	1. Increases focal plane complexity, increases data rate, and requires faster optics.
2. Increase bandwidth to increase sensitivity.	2. May be prohibited by objectives of EDRs.

SUGGESTED FUTURE STUDY AREAS

1. Evaluation of the impacts on this sensor of the results of the EDR flowdown, sensor wavelength, bandpass, and sensitivity studies.
2. Evaluation of the impacts of the results of the calibration study on this sensor.
3. The development of a complete thermal model for the sensor.
4. Investigation of the risks and benefits of integrating the Fabry lenses onto the radiometric detectors.
5. Investigation of the use of continuously resizable field stops to smoothly control sensor resolution over all scan angles.
6. Investigation of the use of electronic techniques to control the effective detector size and thus control sensor resolution over all scan angles.
7. Study of the impacts of incorporating flyback or a variable scan rate, and the associated need for momentum compensation.
8. Investigation of the optimum method for sampling, resampling, smoothing, and/or compressing the data to reduce the sensor data rate.
9. The study of trades to determine the optimum way to recover 0.65 Km resolution for the last 1.25 degrees of scan range.
10. The study of the imaging characteristics of the sensor consisting of the application of the calculated system point functions to real and synthetic scenes for various sampling methods to characterize the ability of the sensor to detect features at the sensitivity and resolution limits of the sensor, and to investigate the impacts of having a variable resolution over a scene.
11. Investigation of the impacts of making use of modern image restoration techniques to recover sub-pixel detail from scenes.